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SOIL EROSION AT THREE EXPERIMENTAL SITES IN THE MEDITERRANEAN

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ABSTRACT

The results of erosion studies carried out at three representative sites in the European Mediterranean basin are discussed. The objectives of the study are to clarify the underlying processes affecting soil erosion and to quantify erosion and runoff in the framework of mitigation of land degradation. The study was carried out at three instrumented field stations using similar layouts and experimental set-ups and harmonized field procedures. Runoff and sediment yield from bounded plots were measured for different types of land use for longer periods.

The runoff and sediment values were found to be relatively low, and showed average annual values between 2·0 and 8·9 l m^{-2} for runoff, and between 20·2 and 28·1 g m^{-2} for sediment yield. The results show that the individual plot response on an event basis shows no relationship between runoff and sediment yield for two of the three sites. On an annual average basis a significant relationship is found between the runoff and sediment yield. Significant differences were observed between different types of land use, especially between semi-natural vegetation, burned and abandoned field cover types on the one hand, and agricultural fields on the other hand. The runoff and erosion values were lowest for the semi-natural fields. It was found that in non-cultivated fields the bounded plots might suffer from depletion of available sediment.

It can be concluded that erosion figures are very low for the sites studied, and that the maintenance of semi-natural vegetation may help in the prevention of runoff generation and erosion. It can be concluded that the use of bounded plots may not be as ideal as might be expected from its wide application. In some cases open plots, especially under semi-natural land use, may produce much better results, especially when measuring over longer periods.

KEY WORDS: erosion plots; sediment yield; runoff; land use; vegetation cover; Mediterranean

INTRODUCTION AND OBJECTIVES

In this study the results of soil erosion research at three representative Mediterranean sites are presented. It is often claimed that soil erosion is an important problem in the Mediterranean as a result of adverse human impact (Fantechi and Margaris, 1986; Jeftic *et al.*, 1993). This can be due to processes which act on a local, regional or even global scale, such as land use change or climate change. These processes have been varying in space and time substantially at least for the last 4000 years within the Mediterranean basin (Brandt and Thornes, 1996). However, current changes are mainly driven by socio-economic forces, due to enlargement of economic markets on a European and global scale, which will be reflected in land use change. These often affect land cover and tillage practices, both of which influence erosion processes. Due to these changes, a better understanding of the underlying processes of land degradation is needed, as well as an improved

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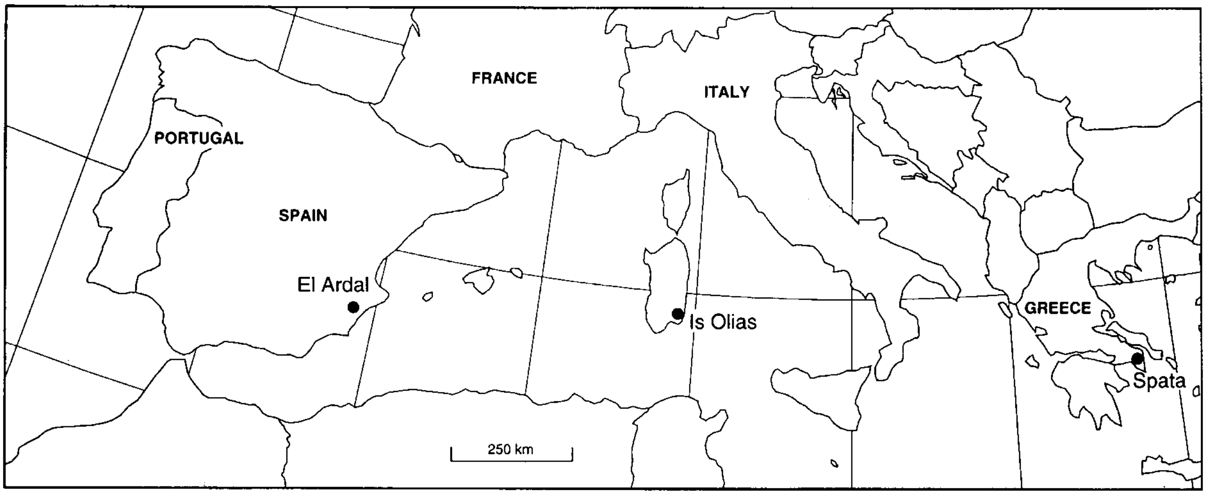

Figure 1. Location map of the three research areas

quantification of degradation rates in semi-arid and sub-humid areas in the Mediterranean under both natural and human-induced circumstances. However, reliable data sets, which should cover more than one area and be based on long monitoring periods, are scarce. Furthermore, the available data are often not comparable due to different goals and methodologies applied, as well as different climatological regimes, land use and substratum properties over the Mediterranean basin.

Much work has been carried out to determine the actual soil erosion rates under Mediterranean conditions and the results show large variations in sediment yield and runoff. This was found to be strongly related to land use change or management (Bryan and Campbell, 1986; Kosmas *et al.*, 1997), vegetation cover (Francis and Thornes, 1990) and stone cover (Poesen *et al.*, 1994). Distinction should be made between erosion phenomena in badlands (lithological deserts), and erosion in areas with non-dispersive materials. Rates of erosion found in badland areas, although important, are put forward as representative for Mediterranean areas as a whole, but this is not the case. Many regions with other types of substratum also show important signs of soil erosion and other types of land degradation.

In this study the results from three field sites (situated in Italy, Greece and Spain, Figure 1), of the MEDALUS project (Brandt and Thornes, 1996) are compared and discussed. These sites were especially designed for longer term monitoring, with equal and standardized monitoring designs and as a data-provider for scenario studies based on modelling work (Kirkby *et al.*, 1996). The sites are representative for their environment and give information about soil erosion rates under both natural and agricultural conditions.

The basic objectives of this study are to interpret the runoff and sediment yield results derived from the three field sites in the Mediterranean basin under comparable bioclimatic conditions. The conclusions from the erosion studies carried out at each of the three sites can possibly be applied in finding solutions for soil erosion problems in the Mediterranean basin.

LOCATION AND CHARACTERISTICS OF THE FIELD SITES

The experimental field sites Is Olias in Italy, Spata in Greece and El Ardal in Spain are located in three representative areas which show problems of desertification including deterioration and depletion of soil properties and water resources, desiccation and decreasing biomass production, as well as signs of adverse land use management (Lopez-Bermudez, 1990; Puddu *et al.*, 1995; Vacca *et al.*, 1995; Yassoglou, 1989).

The Mediterranean climate is the common factor for the three sites. The temperature regime is more or less equal, but the rainfall has a more semi-arid character at the Spanish site, with an average annual precipitation

Table I. Experimental fields characteristics

Experimental field	Country, Province	Geographic coordinates	Altitude (m a.s.l.)	Average temperature (°C)	Average rainfall (mm)	Type of climate	Lithology	Soil use
Is Olias	Italy, Sardinia	39° 11′ N, 8° 57′ E	60–253	17·0	540	Mediterranean	Holocene, Pleistocene slope deposits and metamorphic rocks	Abandoned grazing, burned Macchia and *Eucalyptus*
Spata	Greece, Athens	37° 58′ N, 23° 55′ E	140	17·8	496	Thermo-mediterranean	Marls and sandstones	Olives and vines
El Ardal	Spain, Murcia	38° 04′ 30 N, 1° 32′ 18 W	550	17·0	300	Mediterranean semi-arid	Limestones and conglomerates	Scrubland, barley and wheat, fallow land

Table II. Characteristics of the plots, Is Olias experimental field

	Hillslope 1			Hillslope 2			Hillslope 3		
Plot	1,2	3,4	5,6	7,8	9,10	11,12	13,14	15,16	17,18
Slope (%)	17·6	17·6	12·2	36·3	46·6	34·4	31·5	23·0	12·2
Surface stoniness (%)	70	85	72	43	60	72	65	63	37
Vegetation cover (%)	60–70	50–55	60–70	80–90	50–70	50–80	25–30	25–30	20–25
Org. C (%)	2·0	n.d.	3·2	4·3	n.d.	7·5	2·2	1·3	0·5
Sand (%)	55	n.d.	56	51	n.d.	53	39	48	73
Silt (%)	29	n.d.	30	33	n.d.	34	39	34	5
Clay (%)	16	n.d.	14	16	n.d.	13	22	18	22
Lithology	Holocene slope deposits			Palaeozoic metamorphic rock			Pleistocene slope deposits		
Land Use	Abandoned fields with *Cistus* sp. with grasses			Burned macchia with *Cistus* sp. and grasses			*Eucalyptus globulus* and *E. camaldulensis*		
Type of soil	Typic Xerochrept			Ultic Haploxeroll		Typic Xerochrept	Typic Fragiochrept	Typic Fragixeralf	Typic Haploxerult

Table III. Characteristics of the plots, Spata experimental field

	Transect A			Transect B		
Plot	1	2	3	4	5	6
Slope (%)	17·2	18·0	22·3	12·4	9·3	7·0
Surface stoniness (%)	29·0	20·9	34·2	19·0	9·6	10·9
Vegetation cover (%)	44–95*	44–95*	44–95*	0–10	0–10	0–10
Org. C (%)	1·22	1·57	1·8	1·1	0·9	0·9
Sand (%)	39·3	39·6	28·1	22·0	31·0	34·4
Silt (%)	39·3	32·0	35·4	48·9	38·9	31·2
Clay (%)	21·4	28·4	36·5	29·1	30·1	34·4
Lithology	Marl and sandstones			Marl and sandstones		
Land use	Olives			Vines		
Type of soil	Typic or Calcic Xerochrepts			Typic or Calcic Xerochrepts		

* Vegetation cover strongly dependent on the season

of 300 mm, whereas the Spata site in Greece receives 496 mm and the Sardinian site 540 mm per year. In the Spanish site it was very dry in the period under discussion, 1991–1994. However, the precipitation of the Mediterranean basin has a high inter-annual variability: there can be high rainfall intensities and all sites have a clear summer drought (Lopez-Bermudez, 1991; Sezione Autonoma per il Servizio Idrografico della Sardegna, 1991) In Table I the main characteristics of the sites are indicated with regard to physical setting and land use types. More detailed information on the specific conditions and properties is given in Tables II, III and IV for the three field sites. Tables II–IV give the range of vegetation cover, which is related to the seasonal fluctuation of annuals.

The field site at Is Olias (Table II) is situated in the Rio Santa Lucia catchment in the commune of Assemini in southern Sardinia, Italy. The relatively high frequency of flash floods in the autumn and winter is significant as far as erosion is concerned. For Sardinia three representative areas have been studied to assess the effects of soil erosion. The areas concerned are abandoned grazing land, which is now invaded by shrubs (hillslope 1), ‘macchia’ (open, shrubby, semi-natural vegetation) burned in June 1991 (hillslope 2) and a *Eucalyptus* plantation (hillslope 3); all three areas are situated along northeast-facing slopes.

The study area at Spata (Table III) is located approximately 30 km northeast of Athens and is situated on a hillslope draining to a flat alluvial plain. Research is carried out on two land use types with olive groves and rain-fed vineyards.

The experimental site of El Ardal (Table IV) is located in the basin of the Rio Mula. The calcareous soils are shallow and show high permeabilities and the bare areas in between the shrubs have much more compacted and less permeable topsoils (Martinez-Fernandez *et al.*, 1995). Land use is changing from grazed shrubland (Martinez-Fernandez *et al.*, 1994) on top of the hillslope via abandoned fields to rainfed cereals in the valley bottom.

METHODOLOGY

Runoff and sediment production were measured at all the experimental areas on bounded erosion plots. The plots are of Wischmeier type (Wischmeier and Smith, 1978) but are smaller in size than the original ones. Bounded plots were designed to be able to directly determine runoff per unit surface area. Each plot was trenched around to lead runoff water away up-slope. Runoff was drained into large containers installed in the ground following predefined layouts and protocols (Cammeraat, 1996). The containers were cleared of sediments and water periodically, and after each rainfall event.

Together with the measurement of runoff and sediment loss, which is the primary aim of this study, soil nutrient loss, soil moisture content, vegetation cover, species composition and above and below ground

Table IV. Characteristics of the plots, El Ardal experimental field

	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17
Slope (%)	7	7	7	7	28	28	22	22	11	11	7	7	20	20	11	22	22
Land use*	C	F	F	F	CS	S	S	CS	S	CS	F	C	F	F	S	S	S
Vegetation cover (%)	0–90	10–30	10–30	0–10	10–30	10–70	65–70	10–20	65–70	10–20	5–20	0–90	10–60	30–60	20–30	45–50	10–20
Org. C (%)	1·7	1·1	1·1	1·1	5·4	5·4	5·4	5·4	5·4	5·4	1·1	1·7	1·1	1·1	5·4	5·4	5·4
Sand (%)	37·5	55·6	55·6	55·6	32·1	32·1	32·1	32·1	32·1	32·1	55·6	37·5	55·6	55·6	32·1	32·1	32·1
Silt (%)	41·4	31·6	31·6	31·6	45·4	45·4	45·4	45·4	45·4	45·4	31·6	41·4	31·6	31·6	45·4	45·4	45·4
Clay (%)	21·1	12·8	12·8	12·8	22·5	22·5	22·5	22·5	22·5	22·5	12·8	21·1	12·8	12·8	22·5	22·5	22·5
Lithology	Limestones and conglomerates																
Type of soil	Xerollic Paleorthids																

* C = crops (plot 1 barley; plot 12 wheat); F = fallow (plot 2,3,4,11,13,14); S = scrubland (6,7,9,15,16,17); CS = cut scrubland (plot 5,8,10).

Table V. Erosion and runoff plot characteristics of the three field sites

Location	Treatment	Number of plots	Size (length × width, m)	Measurement period
Is Olias	Abandoned	6	10 × 2	Sept 92–Aug 94
	Burnt	6	10 × 2	
	Eucalypt	6	10 × 2	
Spata	Olive grove	6	10 × 2	April 91–March 94
	Vineyard	6	10 × 2	
El Ardal	Cereals	2	8 × 2	Jan 91–Aug 94
	Fallow*	6	8 × 2 + 2: 10 × 2	
	Shrubs	6	8 × 2 + 3: 10 × 2	
	Cut shrubs	3	8 × 2	

* Different types of soil cover, with respect to stone density, tillage, crop removal and annual cover

biomass production were determined, forming part of a larger field research framework. In Table V the size, treatment and number of plots per site and treatment are indicated; cover types in each plot can be found in Tables II–IV. Additionally, data were gathered on the role of rock fragments and soil cover, and the effects of land abandonment on soil properties with respect to soil degradation.

Vegetation cover and rock fragment cover were measured using grid-counting methods. During the analysis of vegetation cover in relation to other properties or processes, the lowest cover data observed were used. Statistical analysis was carried out using standard ANOVA and correlation methods.

RESULTS AND DISCUSSION

Runoff–erosion relationships

Many factors play an important role in hydrological and erosion processes, of which soil type, cover type and percentage, land use and rainfall erosivity are expected to be important. Soil erosion and runoff generation are a complex function of rainfall, soil and other factors, as noted by many other researchers (Wischmeier *et al.*, 1971; Luk, 1979; Lal, 1988; Bajaracharya and Lal, 1992). Runoff and erosion response, and the effects of land use and cover type are discussed below, as well as the influence of both rock fragment and vegetation cover.

The analysis of the results of individual events in the period 1991–1994 did not show a direct relationship between rainfall, runoff and soil loss at the Is Olias and El Ardal sites. A high correlation between runoff and sediment yield on an event basis was found ($R = 0{\cdot}85$) only for the Spata site. The sediment yield (SL, in g m^{-2}) was found to be a power function of runoff (D, in mm) expressed in the equation: $SL = 7{\cdot}3\ D^{1{\cdot}44}$ ($n = 25$). This relation was found to be much poorer for the Spata plots 1–3 because of the much lower runoff and sediment yield values.

It was observed that heavy storms do not necessarily coincide with high amounts of runoff or sediments, as shown by the example from the Is Olias site (Table VI). Furthermore, for the same rainfall event, adjacent plots may show a high variabilty in runoff and sediment yield (Table VII). This spatial variability between plots with similar cover types was found especially at the Is Olias and El Ardal sites, but is also described in other studies (e.g. Wendt et *al*., 1986), and is of major concern in erosion modelling (Nearing, 1998). This problem is also reflected by the fact that models running on annual data generally predict more accurately (Favis-Mortlock, 1998). This might be related to the reduction in variability, given that inter-annual variation is commonly smaller than intra-annual variation, and to the avaraging out of variability over longer time-spans.

Table VI. Runoff and sediment yield from rainfall events with different intensities for runoff plot 11 (hillslope 2), Is Olias site

Date	Rainfall (mm)	I30 max (mm)	Runoff (l m^{-2})	Sediment yield (g m^{-2})
02.11.92	17·4	3·0	0·054	0·004
18.11.92	16·0	2·0	0·064	0·092
05.12.92	12·2	4·4	0·401	0·133
27.02.93	9·0	3·0	0·070	0·200
01.03.93	26·4	3·8	0·237	0·115
03.03.93	32·0	3·2	0·690	0·098
10.03.93	3·8	1·4	0·018	0·010
15.03.93	5·4	3·8	0·022	0·044
19.04.93	4·8	1·8	0·024	0·034
26.04.93	6·0	0·8	0·039	0·078
28.04.93	26·6	9·6	0·290	0·136
01.05.93	4·0	1·6	0·047	0·019
03.05.93	5·4	2·8	0·047	0·029
14.05.93	6·8	3·8	0·020	0·044
23.06.93	4·8	1·6	0·010	0·274

Table VII. Examples of runoff and sediment yield for adjacent plots for the same rainfall event, IS Olias site

Date	Plot	Rainfall (mm)	Runoff (l m^{-2})	Sediment yield (g m^{-2})
06.10.92	3	10·0	0·44	0·16
06.10.92	4	10·0	0·12	0·26
06.05.93	3	28·2	0·75	0·24
06.05.93	4	28·2	0·17	0·08
09.12.92	7	26·0	0·60	0·10
09.12.92	8	26·0	0·82	1·70
05.04.93	7	11·4	0·22	0·08
05.04.93	8	11·4	0·12	0·42
24.10.92	17	18·4	0·13	0·10
24.10.92	18	18·4	0·79	0·38
05.12.92	17	17·0	1·90	0·70
05.12.92	18	17·0	0·60	0·83

Table VIII. Correlation matrix between runoff, sediment yield, vegetation cover and stone cover

Site	Characteristic	Sediment yield	Vegetation cover*	Stone cover
El Ardal	Runoff	+ **(0·0010)**	– *(0·088)*	n.d.
	Sediment yield		– *(0·056)*	n.d.
Is Olias	Runoff	+ **(0·0087)**	– **(0·0002)**	– *(0·097)*
	Sediment yield		– (0·476)	– *(0·053)*
Spata	Runoff	+ **(0·006)**	– **(0·011)**	– (0·148)
	Sediment yield		– *(0·0854)*	– **(0·0054)**
All	Runoff	+ **(0·0008)**	– *(0·0663)*	– **(0·0017)**
	Sediment yield		– (0·285)	+ (0·33)

Numbers in bold are significant at the $\alpha < 0{\cdot}05$ level, those in italic between $0{\cdot}05 < \alpha < 0{\cdot}1$ level. Plus sign (+) refers to positive correlation and minus sign (–) to negative correlation. n.d. = not determined

We therefore discuss the runoff and sediment yields not only on an event basis but also on an annual basis. These data are shown in Figure 2A–F for each plot at the three sites. Runoff levels and sediment yield levels are generally low, in the range 1–14 l m^{-2} and 1–110 g m^{-2}, respectively, for the individual plots. The difference in sediment yield and runoff between the different land use types studied at one site is visible for some of the plots. Considering all three sites then the variation in runoff and sediment yield between the contrasting land use types at one site, as shown in Figure 2, seems to be at least as important as the variation between the three sites.

Looking in more detail at the Is Olias site data (Figure 3), the first rains in autumn (October 1992 with 144·4 mm and September 1993 with 92·3 mm), after the dry and hot summers, had the largest impact on the soil with respect to erosion processes. The observed decline in the sediment yield during the study period may be related to the design of the bounded plots. In fact, with this system no new soil material is carried into the plots by overland flow, and the erodible soil material is depleted. The erosion on the three hillslope studied (Figure 2B) is relatively small if compared with the threshold, ranging from 200 to 1200 g m^{-2} per year (Zanchi, 1993), below which soil regeneration in normal pedogenetic processes is sufficient to compensate soil losses. However, it is stressed that under the particular conditions of the study area and of Sardinia in particular, the level of parent material derived by weathering and soil formation is low to very low (Aru *et al.*, 1991).

Figure 4 shows the relationship between runoff and sediment yield for the three different sites. It shows a generally wide scatter, but a significant relationship ($\alpha < 0{\cdot}05$) between runoff and sediment yield was found, on a total basis and without distinction in land use, for all the sites together as well as for the individual sites (Table VIII).

No significant correlations between runoff and sediment yield were found when subdividing for the different types of land use within the sites, except for the fallow and shrubland group of the El Ardal site.

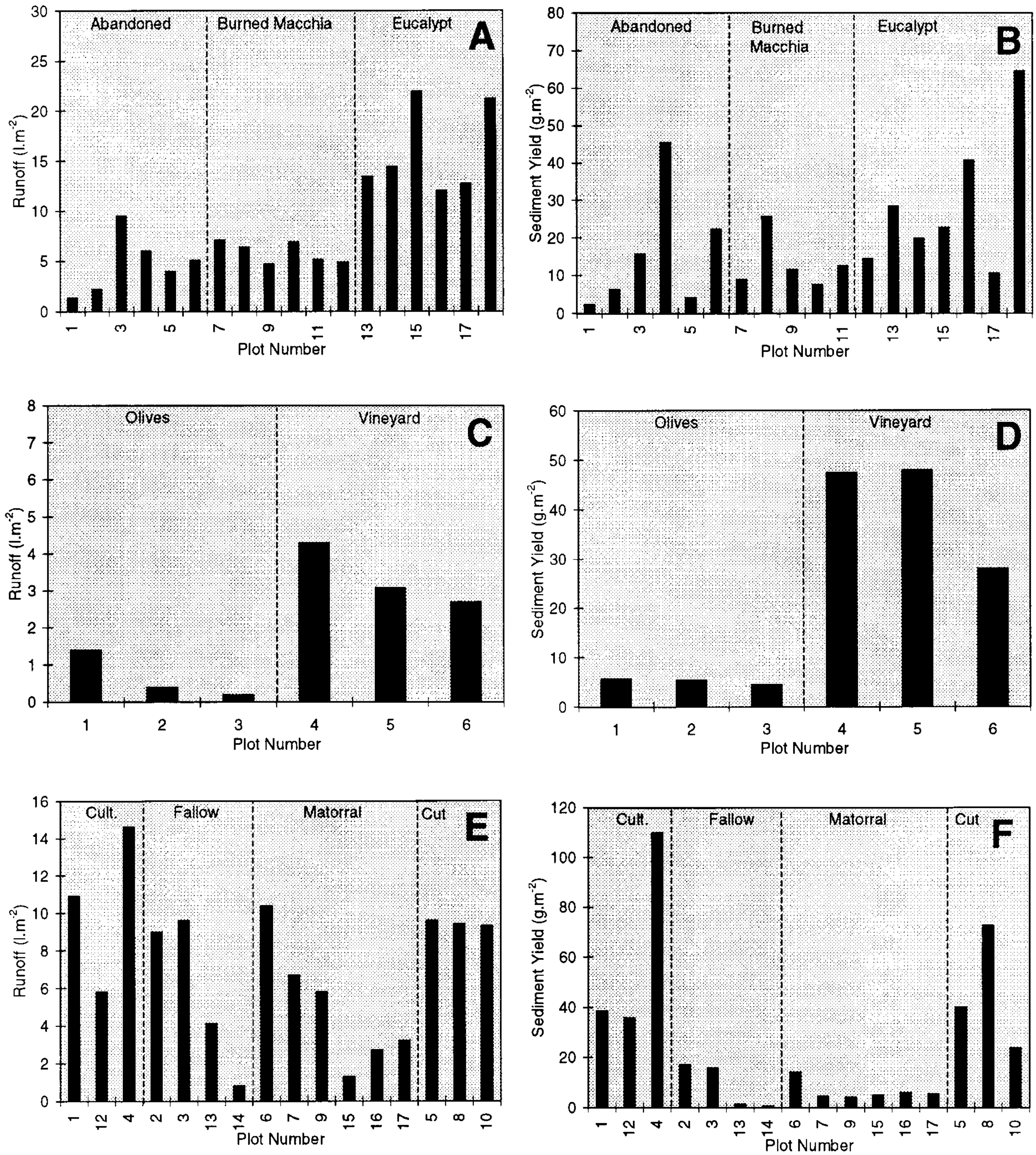

Figure 2. Mean runoff (A) and sediment yield (B) at the Is Olias field site (Italy) for the different plots. Mean runoff (C) and sediment yield (D) at the Spata field site (Greece) for the different plots. Mean runoff (E) and sediment yield (F) at the El Ardal field site (Spain) for the different plots

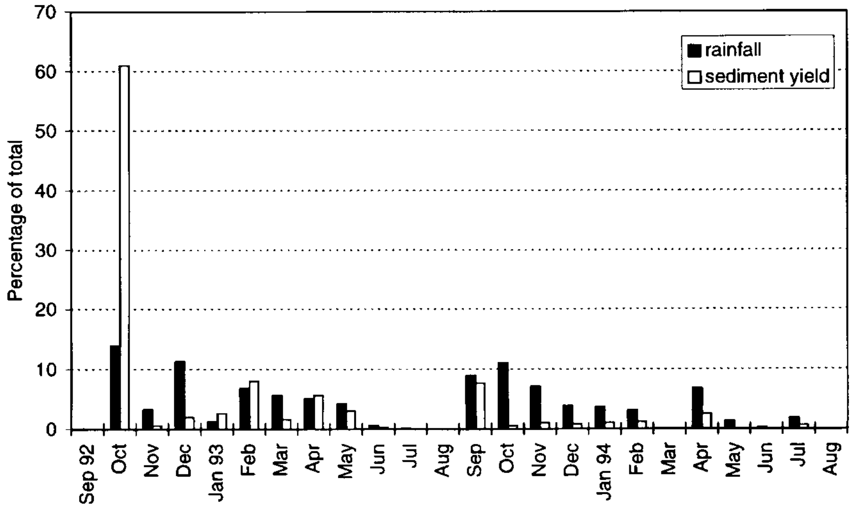

Figure 3. Rainfall and sediment yield (expressed as monthly percentage of the total values recorded during the study period) for all 18 plots at Is Olias

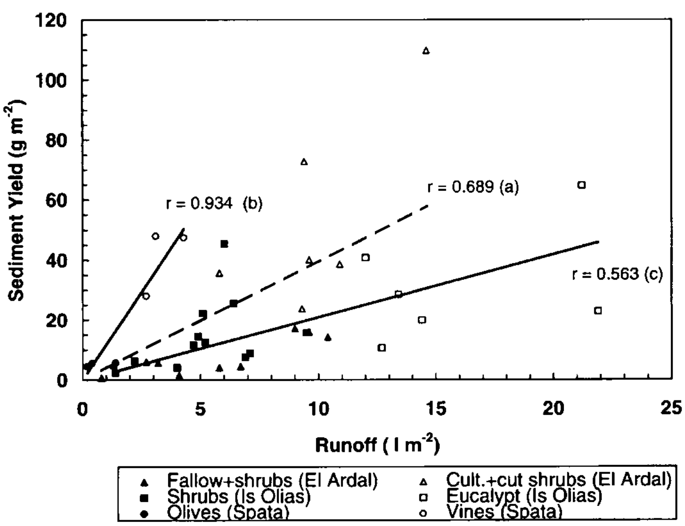

Figure 4. Relationship between mean runoff and sediment yield for all the plots. Trendlines and correlation values relate to the three different sites (a = Is Olias; b = Spata; c = El Ardal). All correlations have a significance better than $\alpha = 0{\cdot}01$

Table IX. Results of ANOVA between types of land use per field site

Location	Factor	Treatment	n	Mean	Std dev.	Sub-set*
El Ardal	Runoff (l m^{-2})	Fallow	4	5·88	4·19	n.s. (0·137)
		Shrubs	6	5·02	3·31	
		Cereal+cultivated	3	10·4	4·42	
		Cleared shrubs	3	9·43	0·15	
	Sediment yield (g m^{-2})	Fallow	4	8·80	8·91	1 (0·01)
		Shrubs	6	6·57	3·80	1
		Cereal+cultivated	3	61·4	42·0	2
		Cleared shrubs	3	45·5	24·9	2
Is Olias	Runoff (l m^{-2})	Shrubland	6	4·70	2·91	1 (0·001)
		Burned	6	5·87	1·06	1
		Eucalypt	6	15·9	4·43	2
	Sediment yield (g m^{-2})	Shrubland	6	16·0	16·3	n.s. (0·121)
		Burned	6	13·5	6·45	
		Eucalypt	6	31·2	19·2	
Spata	Runoff (l m^{-2})	Olives	3	0·67	0·64	1 (0·011)
		Vines	3	3·37	0·83	2
	Sediment yield (g m^{-2})	Olives	3	5·23	0·64	1 (0·005)
		Vines	3	41·2	11·3	2

* The sub-set was defined using the Duncan-Waller procedure, for further classification of ANOVA results. n (0·00x): equal n = the same group; x = significance; n.s., not significant

The effect of land use

From Figure 2A–F it is clear that land use influences runoff and sediment and is at least as important as the differences between the three sites. For example, plot 4, showing highest runoff at the Spata site, is covered by vines, has a soil with low aggregate stability and a slope of 16·7 per cent, and produces the highest amounts of runoff and sediment yield. The average soil loss measured over 155 weeks was found to 77·5 g m^{-2} under olives (plots 1–3), whereas soil loss at the vineyard was seven times as much (576·1 g m^{-2}).

The plots with the highest levels of runoff at the Is Olias site (plots 13 to 18) correspond with *Eucalyptus* plantations, and those plots which show the lowest amounts of runoff (plots 1 to 6) are situated in abandoned fields with natural vegetation. At plots 7 to 12, which have steeper slopes and burned macchia cover type, intermediate levels of runoff and the lowest sediment yields have been found in comparison to the other two hillslopes (Figure 2A, B). These results from the Is Olias site show that in areas with burned macchia and where grazing has been forbidden, runoff is significantly less compared to areas where grazing is continuing, which might be attributed to the regeneration of natural vegetation. The cover of bushes, mainly of *Cistus* sp., has operated as an important erosion control protection but is not as effective as grass cover. The results show the severe erosion of soil under *Eucalyptus* cover, and given the low growing rates of these trees, it is not recommended to plant these trees from an economic point of view.

The effects of land use on sediment yield and runoff are quantified by an ANOVA (Table IX) which indicates that the response of the Eucalypt is significantly different from both burned shrubland and healthy shrubland with regard to runoff. A significant difference between the other two land use types at the Is Olias site could not be demonstrated. For the sediment yield no significant difference was found, which is related to its high variability.

The large impact of land use change on surface runoff at the Spata site is reflected by the values obtained at the two groups of plots, with similar lithology and soil type. The runoff values range between 3·1 and 20·9 l m^{-2} on transect A, whereas on transect B much higher values were found (39·7–63·8 l m^{-2}), which is clearly a significant difference (Table IX and Figure 2C, D). The annual vegetation cover and the plant residues on plots 1–3 prevent soil surface crusting as a result of direct raindrop impact protection. Furthermore, the vegetation diminishes the overland flow velocity. The germination of the vegetation increases the porosity of the upper soil horizon and its infiltration capacity. Under rain with long duration, infiltration in the lower parts of the slopes is considerable for both groups of plots.

In the period of study, southeast Spain suffered from drought, whereas the two other regions had more humid conditions. In general, one could say that during the long period of erosion monitoring in control plots, the amount of erosion is very low at El Ardal. This is attributed to the vegetation cover and the soil types present at this site (Roméro-Díaz *et al.*, 1995). In Table IX different land use types were grouped and their runoff and erosion response subjected to an ANOVA. The results show no significant difference in runoff response between the land uses due to the high standard deviation of runoff. Sediment yield shows a significant difference between fallow areas and shrubby semi-natural vegetation against cereal-covered, tilled and cleared land surfaces. Plots with natural vegetation, either dense or very open, showed much lower erosion rates. This can also be attributed to the effect of water infiltration under the vegetated areas, as these often function as local water sinks (Bergkamp *et al.*, 1996; Puigdefabregas and Sanchez, 1996; Morin and Kosovsky, 1995), preventing concentration of overland flow in rills and gullies. Castillo *et al.* (1997) discuss the effect of vegetation removal on runoff and sediment yield for plots with a comparable setting to the El Ardal site. They found that runoff and sediment yield increased, due to deterioration of the soil surface properties such as increased bulk density, decreased organic matter contents and decreased soil structure. These effects stress the importance of the maintenance or improvement of existing vegetation cover and pattern as a method to improve water infiltration and sediment transport reduction.

Effects of cover

Differences in cover of rock fragments and vegetation cover affect runoff and sediment yield. The role of rock fragments is extensively studied in literature and it has been shown that it has a clear effect on runoff generation. In general, rock fragment cover will increase runoff when the stones are embedded in the soil crust, and will decrease runoff when situated on the soil surface, and this topsoil difference also affects sediment yield (Poesen and Ingelmo-Sanchez, 1992). Vegetation cover has long been recognized as an important factor in runoff generation and erosion protection, as vegetation increases infiltration and surface roughness and reduces the kinetic impact of raindrops (Wischmeier *et al.*, 1971; Morgan, 1991). Therefore the rock fragment cover and vegetation cover were studied to detect any differences in cover within and between the different sites. To relate vegetation cover to runoff and erosion was a problem, as the latter are studied at annual intervals and not on an individual event base. Using the reasonable presumption that erosion and runoff are highest after the drying season and the following wet half year, it was decided to take the lowest observed vegetation cover figures, as these are lowest after the dry period. The results (Table X) show that significant differences in vegetation cover are found between groups of treatments (land use) which is not surprising as they are not independent. For rock fragment cover the grouping of treatments that are significantly different is slightly distinct from the grouping for vegetation cover at the Is Olias site. For the El Ardal no data on rock fragment cover were available based on plot observations so these are excluded from the analysis.

Looking at the Spata site, soil and lithology are the same for both land use types, but a significant difference in soil surface rock fragment cover was found, being lower on plots 4–6 (Table III). A highly significant negative correlation was found between sediment yield (Table VIII) and rock fragment cover. However, it is difficult to explain this result from the rock fragment cover alone, as this goes together with differences in land use. Runoff showed a correlation with rock fragment cover which was far from significant. However, runoff showed a significantly negative correlation with vegetation cover percentage, unlike sediment yield which was only poorly correlated. Again, this correlation is also related to land use as land use determines vegetation cover.

For the El Ardal site a poor negative correlation (significance with $\alpha = 5$–10 per cent) exists between vegetation cover and runoff or sediment yield. The Is Olias site also showed varying correlations between cover and runoff or sediment yield. Only runoff was found to be significantly correlated with vegetation cover, whereas stone cover was only poorly correlated (significance with $\alpha = 5$–10 per cent).

Studying the data for all the sites together, it was found that runoff had a clear negative correlation with stone cover, and a negative correlation with vegetation cover which was almost significant at the $\alpha = 5$ per cent level. For sediment yield these relationships were found to be very poor. The negative correlation

Table X. Results of ANOVA between rock fragment and vegetation cover and land use per field site

Location	Factor	Treatment	*n*	Mean	Std dev.	Sub-set*
El Ardal	Vegetation cover (%)	Fallow	4	15·0	10·0	1 (0·055)
		Shrubs	6	35·8	26·0	1
		Cereal+cultivated	3	0·0	0·0	2
		Cleared shrubs	3	10·0	0·1	2
	Rock fragment cover (%)	n.d.	n.d.	n.d.	n.d.	
Is Olias	Vegetation cover (%)	Shrubland	6	56·6	2·10	1 (0·001)
		Burned	6	60·0	6·32	1
		Eucalypt	6	23·3	1·05	2
	Rock fragment cover (%)	Shrubland	6	7·28	2·97	1 (0·018)
		Burned	6	13·0	5·32	2
		Eucalypt	6	14·0	5·7	2
Spata	Vegetation cover (%)	Olives	3	44·0	0	–
		Vines	3	0	0	
	Rock fragment cover (%)	Olives	3	28·0	6·70	1 (0·038)
		Vines	3	13·2	5·09	2

* The sub-set was defined using the Duncan-Waller procedure, for further classification of ANOVA results. $n(0{\cdot}00x)$: equal n = the same group; x = significance; n.s., not significant;–, no analysis possible

between runoff and both vegetation and rock fragment cover corresponds well with what might be expected from other studies.

CONCLUSIONS

The erosion rates and runoff production at the three experimental sites are generally low. The average annual runoff for the Italian and Spanish sites comparable (8·9 l m^{-2} for Is Olias and 7·1 l m^{-2} for El Ardal but, for Spata in Greece it was much lower (2·0 l m^{-2}). The mean sediment yields were comparable for all three sites (20·2 g m^{-2} for Is Olias, 28·1 g m^{-2} for Spata and 24·2 g m^{-2} for El Ardal). The low amounts of erosion measured can be explained by the fact that none of the three experimental sites is located in an areas where high erosion rates prevail, or where erodible soils occur. However, all the locations have relatively high degradation levels, which is related to past and present overgrazing, adverse land use and tillage practices (Lopez-Bermudez, 1990; Puddu *et al.*, 1995; Vacca *et al.*, 1995).

Especially at the Is Olias site it was noticed that sediment yield might be affected by the use of bounded plots, especially under semi-natural conditions. This can be explained by low soil formation rates in combination with the fact that the plots are disconnected from the natural hillslopes. This prevents the downward influx of water and sediments in upper parts of the plots. Under natural conditions local storage and further transport of sediment on hillslopes under 'Hortonian' overland flow conditions is just as important as in fluviatile environments where it is much more recognized.

There is a poor relationship between runoff and sediment yield on an event basis for two of the three sites. Assuming that during a heavy storm all the plots are affected by the same rainfall intensity, they still show a different response. In particular, the plots at Is Olias and El Ardal show a very individual response, sometimes even with the same land use type. One could say that the plots are only representative for themselves on an event base.

The seasonal and average values, as discussed in this paper, show much more coherent results. At the three sites a significant relationship was found between runoff and erosion, if based on averages and grouped by type of land use. Those plots that show high runoff coefficient are not the same as those that have highest sediment yields.

At the three sites, highest erosion rates were observed in autumn which can be attributed to the higher erosivity of autumn rains, higher erodibility of the soil surface after a warm and dry summer, and the poor soil cover in autumn after the harvest of rainfed crops. From the results obtained from the three areas it seems that the total sediment yield is related to land use and soil cover characteristics, of which the first is the most important.

With respect to land use, it was found at Is Olias, that in an area with macchia shrubland and no grazing, natural vegetation recovery is very good. *Cistus* sp. was found to be an effective plant species against soil erosion. On the other hand, it is not recommended to use *Eucalyptus* trees for reforestation, as soil degradation below these trees was stronger.

At Spata two land use types were compared, vineyards and olive orchards, and a direct relationship was found between land use and generation of runoff, with high runoff values for the vineyards. The change in land use from olives to vines is therefore not recommended in view of the risk of erosion and degradation.

At El Ardal, as at Is Olias, highest erosion was found on slopes with hardly any vegetation or stone cover, whereas lowest erosion rates were found on slopes with a permanent semi-natural vegetation cover. For these latter areas it is recommended not to change semi-natural cover types. From the results of the experimental sites it was concluded that the annual vegetation and plant residues prevent the formation of soil crusts which hamper infiltration, and at the same time reduce overland flow velocities.

The previous findings show that land use here is more important than the soil properties with respect to soil erosion. The impact of land use change on the environmental conditions and especially on soil degradation, such as the replacement of olive trees by vineyards on sloping areas, should be incorporated in decision making and future planning of land use. The vineyards create conditions much more favourable for surface runoff conditions and therefore have a negative impact on erosion and desertification.

The impact of land use on runoff shows the importance of human activity as it contributes to the physical processes of soil erosion. This aspect should be taken seriously by politicians so that they are aware of the appropriate land use and management to prevent further deterioration of soil erosion and land degradation in general in these fragile ecosystems.

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